

MINI-RF: IMAGING RADARS FOR EXPLORING THE MOON. D. B. J. Bussey¹, L. M. Carter², P. D. Spudis³, S. Nozette⁴, C. L. Lichtenberg⁴, R. K. Raney¹, W. Marinelli⁵, and H. L. Winters¹ and the Mini-RF Science team.
¹Applied Physics Laboratory, Laurel MD 20723, ben.bussey@jhuapl.edu, ²Center for Earth and Planetary Studies, Smithsonian Institution, Washington DC 20013, ³Lunar and Planetary Institute, Houston TX 77058, ⁴Naval Air Warfare Center, China Lake CA 93555. ⁵NASA HQ, Washington DC USA

Introduction: Later this year two imaging radars will fly to the Moon to map the polar regions and search for ice. These ice deposits would represent a significant potential resource for the manned human base that is to be set up at one of the Moon's poles late in the next decade. In addition to looking for ice these radars will return data of interest to lunar scientists.

Lunar Ice: The existence of ice in the polar cold traps of the Moon has long been an intriguing possibility [1]. The Clementine spacecraft conducted a radar bistatic experiment in 1994, which supported the idea of an ice deposit within Shackleton crater, near the south pole [2]. However this result generated controversy [3,4] and there is still disagreement whether observed polarization anomalies are due to ice [5]. However there is no argument related to the discovery by Lunar Prospector of enhanced hydrogen levels in the polar regions [6]. The question is whether this hydrogen is in the form of water ice. By mapping the dark areas near the poles and determining the backscattering properties of these surface materials, we will place firm constraints on the nature and occurrence of water ice deposits on the Moon.

The Instruments: An orbiting SAR provides the most robust method of obtaining a positive indication of ice deposits. One big advantage of orbital SARs compared to Earth based radar data is that ALL areas on the Moon can be seen. The 6° inclination of the Moon's orbital plane around the Earth means that large areas of permanent shadow that might contain water ice can never be seen from Earth, and areas that can be seen are viewed at high incidence angles, which reduces the coherent backscatter predicted for ice deposits. However all permanently shadowed regions will be imaged multiple times by an orbiting radar with incidence angles favorable for determining their scattering properties.

The Mini-RF instruments are lightweight SAR radars that will fly on the Indian Space Research Organisation's (ISRO's) Chandrayaan-1 and NASA's Lunar Reconnaissance Orbiter missions. Mini-RF will use a different analytical approach to look for ice. Classically the key parameter used to determine if ice is present is the circular polarization ratio (CPR). This is equal to the same sense (i.e. the left or right sense of the transmitted circular polarization) divided by the opposite sense circular polarization signals that are

received. Volumetric water-ice reflections are known to have larger CPR than usually observed from surface scattering.

Mini-RF will use an hybrid dual polarization technique, transmitting a circular polarized signal (either Right or Left Circular Polarization) and then receiving Horizontal and Vertical polarization signals, as well as the phase information between the two polarizations. This is an unusual architecture, but it preserves all of the information conveyed by the reflected signals. From these data we will determine all four Stokes parameters of the backscattered field. The Stokes parameters offer a very powerful tool to investigate the nature of lunar radar backscatter. In addition to calculating the response at both circular polarizations and the CPR value, it will also be possible to derive properties such as the degree of polarization and the degree of linear polarization, which will help to distinguish between multiple surface reflections versus volume scattering. This is key in trying to determine if the nature of the returned signal is due to an ice-regolith mixture, or simply rocks on the lunar surface.

The Missions: Mini-RF instruments are flying on both the Chandrayaan-1 and LRO missions, both due for launch to the Moon in 2008.

Chandrayaan-1: ISRO's lunar orbiter is scheduled for a Fall 2008 launch. It will conduct a detailed analysis of the lunar surface using eleven instruments over the course of the two year nominal mission from an altitude of 100 km.

The main goal of Mini-RF on Chandrayaan-1 is to conduct systematic SAR mapping polewards of 80° for both poles. Mini-RF will use S-band and have a spatial resolution of 75 meters per pixel. Mini-RF can also operate in a scatterometry or "vertical SAR" mode. In this mode the Chandrayaan-1 spacecraft is rolled so that the antenna is oriented to point to nadir.

Lunar Reconnaissance Orbiter: NASA's LRO is currently scheduled for a late 2008 launch. It is carrying six instruments plus the technology demonstration Mini-RF radar. LRO will orbit the Moon at an altitude of 50 km for a nominal mission duration of one year.

Mini-RF on LRO is an enhanced instrument relative to the one flying on Chandrayaan-1. It operates in both S band (like Chandrayaan-1) and X-band. Also as well as the baseline resolution (75 meters per pixel) it can also operate in zoom mode with a spatial resolu-

tion of 15 meters per pixel. The goal is to target areas already identified by Mini-RF on Chandrayaan-1 as potential ice deposits and use the enhanced capabilities of Mini-RF on LRO to further investigate these areas.

Mini-RF on LRO also has the capability to acquire data applicable for topographic processing. Topography products can be derived using interferometric or SAR stereo techniques. The current mission allocation permits the acquisition of 20 data takes applicable for topographic processing, similar to the SAR Con-Ops.

A third goal of Mini-RF is a communication experiment, which will measure how the Mini-RF technology can be used in a communications role. Mini-RF may act as the back-up communications for the LRO spacecraft.

Additional Science: Whilst most of the mini-RF observations will concentrate on the lunar poles, we hope to acquire additional data of scientifically interesting areas. One area of scientific interest where mini-RF could make a significant contribution is the study of pyroclastic deposits. Pyroclastic deposits record the early history of volcanism on the Moon and they contain mineral resources (metal oxides and volatiles) of potential future use. The dual-polarization capability of mini-RF, combined with information about the geologic setting derived from optical and infrared imagery, can be used to estimate dielectric constants, investigate the amount of surface vs. subsurface scattering, search for areas that are rock poor at the wavelength scale, and estimate the thickness of any thin mantling deposits that that radar wave penetrates [7, 8, 9]. Recent ground-based radar studies of the Moon are a good example of how radar can detect features that are not visible using other remote sensing methods. For example, Arecibo and Green Bank Telescope images of the Aristarchus Plateau at 13-cm wavelength reveal bright streaks that cross some areas of the pyroclastic deposit [9]. Optical images show no corresponding albedo changes; the radar is uniquely able to detect embedded blocky material and locate relatively “rock-free” areas of the deposit. Longer wavelength (70 cm) radar, penetrates through the pyroclastic deposit and detects lava flows buried under ~15 m of mantling material [9].

There are hundreds of mapped pyroclastics deposits on the Moon [10], but it will be particularly interesting to use mini-RF to investigate local areas of large pyroclastics that have complex surrounding terrain (such as Aristarchus), and to investigate pyroclastics that are on the limbs and farside of the Moon, where it is difficult or impossible to obtain radar images from Earth. One potential target is the Orientale pyroclastic deposit, which is an optically dark ring, about 160 km across, on the southwest side of Orientale basin [10,

11, 12]. The ring shape, lack of associated mare deposits, and a visible central source vent make this deposit unique. In ground-based radar images, the incidence angle is very high and shadows prevent a good view of the deposit. Mini-RF observations of the darker parts of the Orientale pyroclastic could help establish its depth and physical properties. As Mini-RF data is acquired over multiple targets, it will also be interesting to compare the radar-derived physical properties of the different pyroclastic deposits.

It is hoped to use both Mini-RF instruments to conduct a spacecraft to spacecraft bistatic imaging experiment (Figure 1). A signal would be transmitted from Mini-RF on Chandrayaan-1 and received by Mini-RF on LRO. Analysis of the returned backscatter signal as a function of phase angle of the same area on the Moon would provide potentially the most definitive remote technique for discriminating between ice and rock units.

Data Availability: All raw data as well as processed data including higher order products such as mosaics will be made available to the scientific community. This will be achieved by archiving of the data to the Geosciences node of the PDS.

References: [1] Watson K. et al., (1961) *JGR*, 66, 3033. [2] Nozette S. et al. (1996) *Science*, 274, 1495. [3] Simpson R. and Tyler L. (1999) *JGR*, 104, 3845. [4] Nozette S. et al. (2001) *JGR*, 106, 23253. [5] Campbell D. et al., (2006) *Nature*, 443, 835. [6] Feldman W. et al., (2001) *JGR*, 106, 23231. [7] Stacy N. (1993) PhD thesis, Cornell. [8] Carter L. et al., (2006) *JGR*, 111, E06005. [9] Campbell B. et al., (2008) *Geology* 36, 135. [10] Gaddis L. et al., (2003) *Icarus* 161, 262. [11] Schultz P.H. and Spudis P.D. (1978) *LPSC IX*, 1033. [12] Bussey D.B.J. and Spudis P.D. (1997) *GRL*, V24 No. 4, 445.

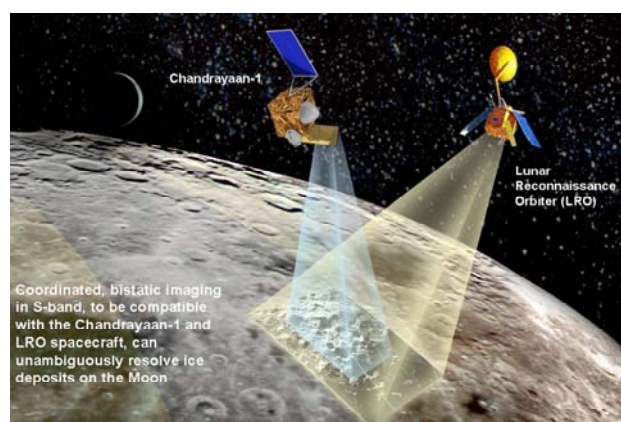


Figure 1. Coordinated bistatic imaging by two orbiting radars will help to discriminate between ice and rock units.